

The clustering of X-ray and sub-mm sources

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Abstract.

It is becoming clear that luminous extragalactic X-ray and sub-mm sources are essentially distinct populations. Thus, if high redshift sub-mm sources represent massive spheroids in formation, there must be a time lag between the major epoch of star-formation and the appearance of a visible quasar. Despite this distinction, I find tentative evidence for a puzzling angular cross-correlation between X-ray sources and bright sub-mm sources in two independent fields. If this signal is due to large-scale structure it would argue for a low redshift ($z < 2$) for many of the SCUBA sources. Alternatively, I suggest that the effect may be enhanced by gravitational lensing. The exceptionally steep slope of the bright sub-mm counts makes this population particularly prone to even moderate lensing bias. An apparent correlation may therefore be produced if X-ray sources trace the intervening large scale structure.

1. Introduction

Our understanding of the high-redshift Universe changed dramatically with the advent of the SCUBA array at the James Clerk Maxwell Telescope. It appears that a significant (perhaps dominant) fraction of the star-formation in the high-redshift Universe ($z > 2$) took place in highly luminous, dust-enshrouded galaxies (Smail et al. 1997, Hughes et al. 1998, Barger et al. 1998, Eales et al. 1999). The discovery of this population was heralded by many as the discovery of the major epoch of dust-enshrouded spheroid formation (Lilly et al. 1999, Dunlop 2001, Granato et al. 2001).

On a similar timescale, it has become clear that essentially every massive galaxy in the local Universe hosts a supermassive black hole (Kormendy & Richstone 1995, Magorrian et al. 1998). In particular, the remarkable relationship between the black hole mass and the spheroidal velocity dispersion suggests a possible link between an early epoch of quasar activity and the formation of the spheroid (Gebhardt et al. 2000, Ferrarese & Merritt 2000).

Observationally, however, it would appear that only a small fraction of SCUBA sources display any signs of powerful AGN activity (Fabian et al. 2000; Severgnini et al. 2000; Hornschemeier et al. 2000). This argues for a time-lag between these two stages of evolution. I present further evidence to support this scenario, combined with a potential detection of clustering between X-ray and sub-mm sources. Possible explanations are briefly discussed.

2. The ELAIS N2 field

The 8mJy SCUBA survey is the largest extragalactic sub-mm survey undertaken to date, covering 260 arcmin^2 in two regions of sky (ELAIS N2 and the Lockman Hole East) to a typical rms noise level of $\sigma = 2.5 \text{ mJy}$ at $850 \mu\text{m}$ (Scott et al. 2002). Chandra observations of the N2 field were presented in Almaini et al. (2002). The main results can be summarised as follows:

(1) Only 1/17 SCUBA sources are detected by Chandra. For the remaining SCUBA sources our X-ray upper limits allow us to strongly rule out an AGN SED, even with a large absorbing column, unless the central engine is completely obscured by Compton-thick material.

(2) We find evidence for angular clustering between the X-ray and sub-mm populations, with a significance of $3.5 - 4\sigma$ within 100 arcsec. This surprising result appears to suggest that a large subset of the two populations are tracing the same large-scale structure (see Figure 1a).

3. The HDF flanking fields

The clustering seen in the ELAIS N2 field clearly requires confirmation in an independent field. Borys et al. (2001) have recently obtained a contiguous, shallow SCUBA scanmap covering an $11 \times 11 \text{ arcmin}$ region centred on the HDF. They find 12 sources brighter than $\sim 10 \text{ mJy}$ with a significance above 3.5σ . For the X-ray population I use the recently published catalogue from the 1Ms Chandra observation of this region (Brandt et al. 2001). To ensure a uniform X-ray coverage across the SCUBA map I choose only the X-ray sources with a flux above $5 \times 10^{-16} \text{ erg s}^{-1} \text{ cm}^{-2}$ ($0.5 - 8.0 \text{ keV}$). Cross-correlating these populations, I obtain a 2.4σ excess of pairs within 100 arcsec.

Barger et al. (2000) have surveyed this region to greater depth with SCUBA by targeting optically-faint radio sources. This is arguably the most efficient way to find SCUBA sources, although somewhat incomplete and potentially biased against very high redshift objects ($z > 3$). Nevertheless, I supplement the Borys et al. catalogue by adding 6 additional sources from Barger et al. to reach a ‘flux limit’ of 7 mJy (comparable with ELAIS N2). With potential biases in mind, we note that the addition of these sources boosts the significance of the cross-correlation signal to 2.9σ within 100 arcsec (see Figure 1b).

4. Discussion

It would appear that only a small fraction of SCUBA sources are detected by Chandra as luminous X-ray sources. The implication is that (for a given galaxy) the major episode of star-formation is essentially distinct from the period of observable quasar activity. Are the black holes in the remaining SCUBA sources dormant, still growing or very heavily obscured? This remains a major unanswered question, which we are currently investigating.

In addition to the low coincidence rate, for two independent fields I find evidence for clustering between bright SCUBA sources and X-ray selected AGN. If this is real large-scale structure the redshift distribution of the X-ray sources

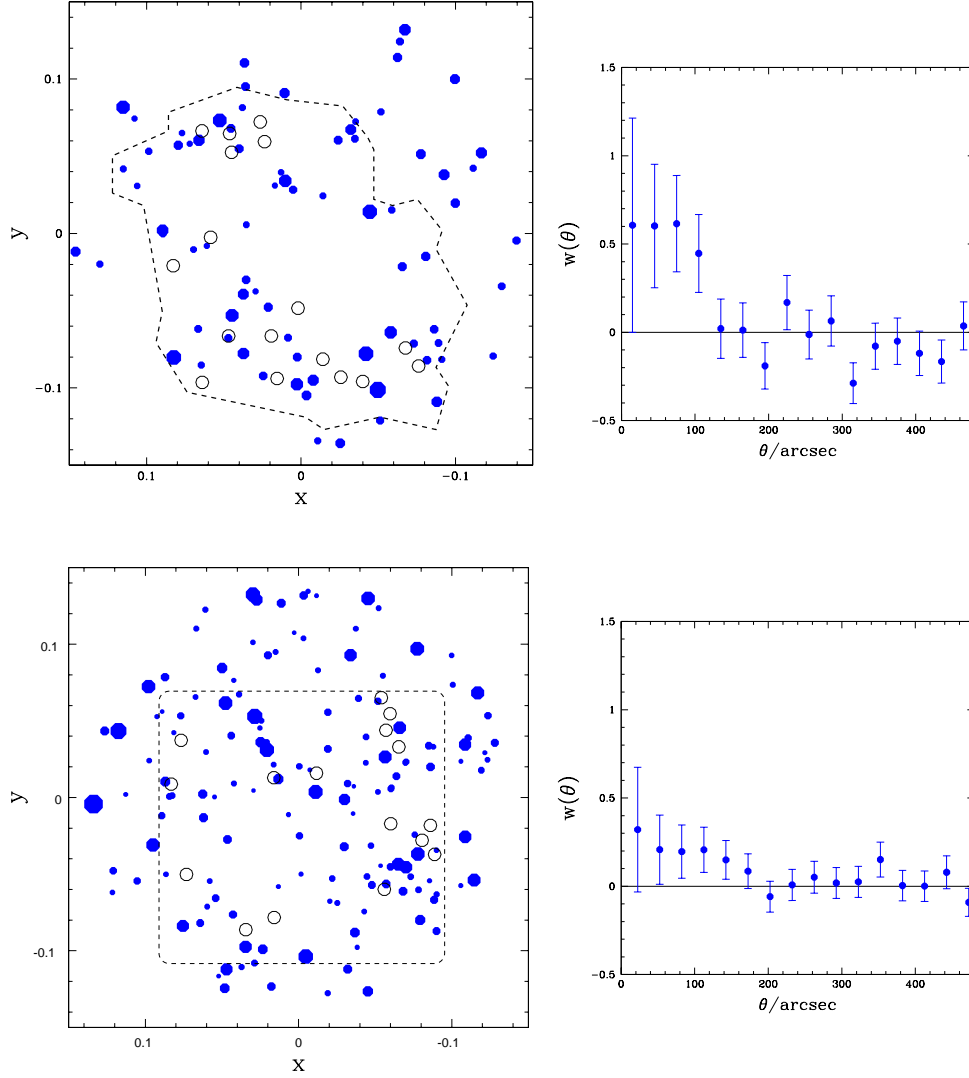


Figure 1. Distribution of X-ray (filled points) and SCUBA sources (open circles) in the ELAIS N2 field (top) and HDF (bottom). The size of the X-ray points are proportional to the log of their flux. The dashed regions show the extent of the SCUBA coverage. A statistical cross-correlation, $w(\theta)$, is shown in each case.

would argue for a large fraction of the SCUBA population lying at $z < 2$. I propose an alternative explanation which invokes gravitational lensing, motivated by the particularly steep sub-mm source counts. In the ‘weak’ lensing regime, for example, where the typical magnification μ is not significantly greater than unity, one can readily demonstrate that a population with cumulative number counts given by a power law of index β will be modified as follows:

$$N'(> S) = \mu^{\beta-1} N(> S) \quad (1)$$

Observed sub-mm number counts have a slope with $\beta \simeq 2.5$ (possibly steepening beyond 8mJy). Foreground large scale structure (e.g. foreground groups) can readily lead to a magnification of $\mu \simeq 1.2 - 1.3$. Thus in the vicinity of such structure one would *expect* an enhancement in number counts of 30 – 50% which could easily produce a positive cross-correlation with foreground populations.

Estimates for the global fraction of lensed sources have been modeled by Blain et al. (1999) and Perrotta et al. (2001) and predicted to be only a few per cent. The fields analysed here may therefore be particularly rich in foreground structure, and this is under investigation. Alternatively, the lensing cross-sections assumed in the models could easily be underestimated (due to halo substructure, for example). In addition, the *intrinsic* slope of the bright sub-mm counts may be turning over more rapidly than previously assumed, perhaps reflecting a steep turn over in the underlying sub-mm luminosity function.

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